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U.S. DEPARTMENT OF COMMERCE/Technology Administration
National Institute of Standards and Technology

Standard Reference Materials:

Acetylene $^{12}C_2H_2$ Absorption Reference for 1510–1540 nm Wavelength Calibration—SRM 2517

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Sarah L. Gilbert and William C. Swann

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Trahey, N.M., ed., NIST Standard Reference Materials Catalog 1995-96, NIST Spec.Publ. 260 (1995 Ed.). PB95-232518/AS

Michaelis, R.E., and Wyman, L.L., Standard Reference Materials: Preparation of White Cast Iron Spectrochemical Standards, NBS Misc. Publ. 260-1 (June 1964). COM74-11061**

Michaelis, R.E., Wyman, L.L., and Flitsch, R., Standard Reference Materials: Preparation of NBS Copper-Base Spectrochemical Standards, NBS Misc. Publ. 260-2 (October 1964). COM74-11063**

Michaelis, R.E., Yakowitz, H., and Moore, G.A., Standard Reference Materials: Metallographic Characterization of an NBS Spectrometric Low-Alloy Steel Standard, NBS Misc.Publ. 260-3 (October 1964). COM74-11060**

Hague, J.L., Mears, T.W., and Michaelis, R.E., Standard Reference Materials: Sources of Information, Publ. 260-4 (February 1965). COM74-11059**

Alvarez, R., and Flitsch, R., Standard Reference Materials: Accuracy of SolutionX-Ray Spectrometric Analysis of Copper-Base Alloys, NBS Misc. Publ. 260-5 (February 1965). PB168068**

Shultz, J.I., Standard Reference Materials: Methods for the Chemical Analysis of White Cast Iron Standards, NBS Misc. Publ. 260-6 (July 1965). COM74-11068**

Bell, R.K., Standard Reference Materials: Methods for the Chemical Analysis of NBS Copper-Base Spectrochemical Standards, NBS Misc.Publ. 260-7 (October 1965). COM74-11067**

Richmond, M.S., Standard Reference Materials: Analysis of Uranium Concentrates at the National Bureau of Standards, NBS Misc.Publ. 260-8 (December 1965). COM74-11066**

Anspach, S.C., Cavallo, L.M., Garfinkel, S.B., et al., Standard Reference Materials: Half Lives of Materials Used in the Preparation of Standard Reference Materials of Nineteen Radioactive Nuclides Issued by the National Bureau of Standards, NBS Misc. Publ. 260-9 (November 1965). COM74-11065**

Yakowitz, H., Vieth, D.L., Heinrich, K.F.J., et al., Standard Reference Materials: Homogeneity Characterization of NBS Spectrometric Standards II: Cartridge Brass and Low-Alloy Steel, NBS Misc. Publ. 260-10 (December 1965). COM74-11064**

Napolitano, A., and Hawkins, E.G., Standard Reference Materials: Viscosity of Standard Lead-Silica Glass, NBS Misc. Publ. 260-11** (November 1966).

Yakowitz, H., Vieth, D.L., and Michaelis, R.E., Standard Reference Materials: Homogeneity Characterization of NBS Spectrometric Standards III: White Cast Iron and Stainless Steel Powder Compact, NBS Misc. Publ. 260-12 (September 1966).

Spijkerman, J.J., Snediker, D.K., Ruegg, F.C., et al., Standard Reference Materials: Mossbauer Spectroscopy Standard for the Chemical Shift of Iron Compounds, NBS Misc. Publ. 260-13** (July 1967).

Menis, O., and Sterling, J.T., Standard Reference Materials: Determination of Oxygen in Ferrous Materials (SRMs 1090, 1091, 1092), NBS Misc. Publ. 260-14** (September 1966).

Passaglia, E. and Shouse, P.J., Standard Reference Materials: Recommended Method of Use of Standard Light-Sensitive Paper for Calibrating Carbon Arcs Used in Testing Testiles for Colorfastness to Light, NBS Spec.Publ. 260-15 (July 1967). Superseded by SP 260-41.

Yakowitz, H., Michaelis, R.E., and Vieth, D.L., Standard Reference Materials: Homogeneity Characterization of NBS Spectrometric Standards IV: Preparation and Microprobe Characterization of W-20% Mo Alloy Fabricated by Powder Metallurgical Methods, NBS Spec. Publ. 260-16 (January 1969). COM74-11062**

Catanzaro, E.J., Champion, C.E., Garner, E.L., et al., Standard Reference Materials: Boric Acid; Isotopic, and Assay Standard Reference Materials, NBS Spec. Publ. 260-17 (February 1970). PB189457**

Geller, S.B., Mantek, P.A., and Cleveland, N.G., Calibration of NBS Secondary Standards Magnetic Tape Computer Amplitude Reference Amplitude Measurement "Process A," NBS Spec. Publ. 260-18 (November 1969). Superseded by SP 260-29.

Paule, R.C., and Mandel, J., Standard Reference Materials: Analysis of Interlaboratory Measurements on the Vapor Pressure of Gold (Certification of SRM 745). NBS Spec. Publ. 260-19 (January 1970). PB190071**

260-20: Unassigned

Paule, R.C., and Mandel, J., Standard Reference Materials: Analysis of Interlaboratory Measurements on the Vapor Pressures of Cadmium and Silver, NBS Spec. Publ. 260-21 (January 1971). COM74-11359**

Yakowitz, H., Fiori, C.E., and Michaelis, R.E., Standard Reference Materials: Homogeneity Characterization of Fe-3 Si Alloy, NBS Spec. Publ. 260-22 (February 1971). COM74-11357**

Napolitano, A., and Hawkins, E.G., Standard Reference Materials: Viscosity of a Standard Borosilicate Glass, NBS Spec. Publ. 260-23 (December 1970). COM71-00157**

Sappenfield, K.M., Marinenko, G., and Hague, J.L., Standard Reference Materials: Comparison of Redox Standards, NBS Spec. Publ. 260-24 (January 1972). COM72-50058**

Hicho, G.E., Yakowitz, H., Rasberry, S.D., et al., Standard Reference Materials: A Standard Reference Material Containing Nominally Four Percent Austenite, NBS Spec. Publ. 260-25 (February 1971). COM74-11356**

Martin, J.F., Standard Reference Materials: NBS-U.S. Steel Corp. Joint Program for Determining Oxygen and Nitrogen in Steel, NBS Spec. Publ. 260-26 (February 1971). PB 81176620**

Garner, E.L., Machlan, L.A., and Shields, W.R., Standard Reference Materials: Uranium Isotopic Standard Reference Materials, NBS Spec. Publ. 260-27 (April 1971). COM74-11358**

Heinrich, K.F.J., Myklebust, R.L., Rasberry, S.D., et al., Standard Reference Materials: Preparation and Evaluation of SRMs 481 and 482 Gold-Silver and Gold-Copper Alloys for Microanalysis, NBS Spec. Publ. 260-28 (August 1971). COM71-50365**

Geller, S.B., Standard Reference Materials: Calibration of NBS Secondary Standard Magnetic Tape (Computer Amplitude Reference) Using the Reference Tape Amplitude Measurement "Process A-Model 2," NBS Spec. Publ. 260-29 (June 1971). COM71-50282** Supersedes Measurement System in SP 260-18.

Gorozhanina, R.S., Freedman, A.Y., and Shaievitch, A.B., (translated by M.C. Selby), Standard Reference Materials: Standard Samples Issued in the USSR (A Translation from the Russian), NBS Spec. Publ. 260-30 (June 1971). COM71-50283**

Hust, J.G., and Sparks, L.L., Standard Reference Materials: Thermal Conductivity of Electrolytic Iron SRM 734 from 4 to 300 K, NBS Spec. Publ. 260-31 (November 1971). COM71-50563**

Mavrodineanu, R., and Lazar, J.W., Standard Reference Materials: Standard Quartz Cuvettes for High Accuracy Spectrophotometry, NBS Spec. Publ. 260-32 (December 1973). COM74-50018**

Wagner, H.L., Standard Reference Materials: Comparison of Original and Supplemental SRM 705, Narrow Molecular Weight Distribution Polystyrene, NBS Spec. Publ. 260-33 (May 1972). COM72-50526**

Sparks, L.L., and Hust, J.G., Standard Reference Material: Thermoelectric Voltage of Silver-28 Atomic Percent Gold Thermocouple Wire, SRM 733, Verses Common Thermocouple Materials (Between Liquid Helium and Ice Fixed Points), NBS Spec. Publ. 260-34 (April 1972). COM72-50371**

Sparks, L.L., and Hust, J.G., Standard Reference Materials: Thermal Conductivity of Austenitic Stainless Steel, SRM 735 from 5 to 280 K, NBS Spec. Publ. 260-35 (April 1972). COM72-50368**

Cali, J.P., Mandel, J., Moore, L.J., et al., Standard Reference Materials: A Reference Method for the Determination of Calcium in Serum NBS SRM 915, NBS Spec. Publ. 260-36 (May 1972). COM72-50527**

Shultz, J.I., Bell, R.K., Rains, T.C., et al., Standard Reference Materials: Methods of Analysis of NBS Clay Standards, NBS Spec. Publ. 260-37 (June 1972). COM72-50692**

Richard, J.C., and Hsia, J.J., Standard Reference Materials: Preparation and Calibration of Standards of Spectral Specular Reflectance, NBS Spec. Publ. 260-38 (May 1972). COM72-50528**

Clark, A.F., Denson, V.A., Hust, J.G., et al., Standard Reference Materials: The Eddy Current Decay Method for Resistivity Characterization of High-Purity Metals, NBS Spec. Publ. 260-39 (May 1972). COM72-50529**

McAdie, H.G., Garn, P.D., and Menis, O., Standard Reference Materials: Selection of Differential Thermal Analysis Temperature Standards Through a Cooperative Study (SRMs 758, 759, 760), NBS Spec. Publ. 260-40 (August 1972) COM72-50776**

Wood. L.A., and Shouse, P.J., Standard Reference Materials: Use of Standard Light-Sensitive Paper for Calibrating Carbon Arcs Used in Testing Textiles for Colorfastness to Light, NBS Spec. Publ. 260-41 (August 1972). COM72-50775**

Wagner, H.L., and Verdier, P.H., eds., Standard Reference Materials: The Characterization of Linear Polyethylene, SRM 1475, NBS Spec. Publ. 260-42 (September 1972). COM72-50944**

Yakowitz, H., Ruff, A.W., and Michaelis, R.E., Standard Reference Materials: Preparation and Homogeneity Characterization of an Austenitic Iron-Chromium-Nickel Alloy, NBS Spec. Publ. 260-43 (November 1972). COM73-50760**

Schooley, J.F., Soulen, R.J., Jr., and Evans, G.A., Jr., Standard Reference Materials: Preparation and Use of Superconductive Fixed Point Devices, SRM 767, NBS Spec. Publ. 260-44 (December 1972). COM73-50037**

Greifer, B., Maienthal, E.J., Rains, T.C., et al., Standard Reference Materials: Development of NBS SRM 1579 Powdered Lead-Based Paint, NBS Spec. Publ. 260-45 (March 1973). COM73-50226**

Hust, J.G., and Giarratano, P.J., Standard Reference Materials: Thermal Conductivity and Electrical Resistivity Standard Reference Materials: Austenitic Stainless Steel, SRMs 735 and 798, from 4 to 1200 K, NBS Spec. Publ. 260-46 (March 1975). COM75-10339**

Hust, J.G., Standard Reference Materials: Electrical Resistivity of Electrolytic Iron, SRM 797, and Austenitic Stainless Steel, SRM 798, from 5 to 280 K, NBS Spec. Publ. 260-47 (February 1974). COM74-50176**

Mangum, B.W., and Wise, J.A., Standard Reference Materials: Description and Use of Precision Thermometers for the Clinical Laboratory, SRM 933 and SRM 934, NBS Spec. Publ. 260-48 (May 1974). Superseded by NIST Spec. Publ. 260-113. COM74-50533**

Carpenter, B.S., and Reimer, G.M., Standard Reference Materials: Calibrated Glass Standards for Fission Track Use, NBS Spec. Publ. 260-49 (November 1974). COM74-51185**

Hust, J.G., and Giarratano, P.J., Standard Reference Materials: Thermal Conductivity and Electrical Resistivity Standard Reference Materials: Electrolytic Iron, SRMs 734 and 797 from 4 to 1000 K, NBS Spec. Publ. 260-50 (June 1975). COM75-10698**

Mavrodineanu, R., and Baldwin, J.R., Standard Reference Materials: Glass Filters As a SRM for Spectrophotometry-Selection, Preparation, Certification, and Use-SRM 930 NBS Spec. Publ. 260-51 (November 1975). COM75-10339**

Hust, J.G., and Giarratano, P.J., Standard Reference Materials: Thermal Conductivity and Electrical Resistivity SRMs 730 and 799, from 4 to 3000 K, NBS Spec. Publ. 260-52 (September 1975). COM75-11193**

Durst, R.A., Standard Reference Materials: Standardization of pH Measurements, NBS Spec. Publ. 260-53 (December 1978). Superseded by SP 260-53 Rev. 1988 Edition. PB88217427**

Burke, R.W., and Mavrodineanu, R., Standard Reference Materials: Certification and Use of Acidic Potassium Dichromate Solutions as an Ultraviolet Absorbance Standard, NBS Spec. Publ. 260-54 (August 1977). PB272168**

Ditmars, D.A., Cezairliyan, A., Ishihara, S., et al., Standard Reference Materials: Enthalpy and Heat Capacity; Molybdenum SRM 781, from 273 to 2800 K, NBS Spec. Publ. 260-55 (September 1977). PB272127**

Powell, R.L., Sparks, L.L., and Hust, J.G., Standard Reference Materials: Standard Thermocouple Material, Pt-67: SRM 1967, NBS Spec. Publ. 260-56 (February 1978). PB277172**

Cali, J.P., and Plebanski, T., Standard Reference Materials: Guide to United States Reference Materials, NBS Spec. Publ. 260-57 (February 1978). PB277173**

Barnes, J.D., and Martin, G.M., Standard Reference Materials: Polyester Film for Oxygen Gas Transmission Measurements SRM 1470, NBS Spec. Publ. 260-58 (June 1979). PB297098**

Chang, T., and Kahn, A.H., Standard Reference Materials: Electron Paramagnetic Resonance Intensity Standard: SRM 2601; Description and Use, NBS Spec. Publ. 260-59 (August 1978). PB292097**

Velapoldi, R.A., Paule, R.C., Schaffer, R., et al., Standard Reference Materials: A Reference Method for the Determination of Sodium in Serum, NBS Spec. Publ. 260-60 (August 1978). PB286944**

Verdier, P.H., and Wagner, H.L., Standard Reference Materials: The Characterization of Linear Polyethylene (SRMs 1482, 1483, 1484), NBS Spec. Publ. 260-61 (December 1978). PB289899**

Soulen, R.J., and Dove, R.B., Standard Reference Materials: Temperature Reference Standard for Use Below 0.5 K (SRM 768), NBS Spec. Publ. 260-62 (April 1979). PB294245**

Velapoldi, R.A., Paule, R.C., Schaffer, R., et al., Standard Reference Materials: A Reference Method for the Determination of Potassium in Serum, NBS Spec. Publ. 260-63 (May 1979). PB297207**

Velapoldi, R.A., and Mielenz, K.D., Standard Reference Materials: A Fluorescence SRM Quinine Sulfate Dihydrate (SRM 936), NBS Spec. Publ. 260-64 (January 1980). PB80132046**

Marinenko, R.B., Heinrich, K.F.J., and Ruegg, F.C., Standard Reference Materials: Micro-Homogeneity Studies of NBS SRM, NBS Research Materials, and Other Related Samples, NBS Spec. Publ. 260-65 (September 1979). PB300461**

Venable, W.H., Jr., and Eckerle, K.L., Standard Reference Materials: Didymium Glass Filters for Calibrating the Wavelength Scale of Spectrophotometers (SRMs 2009, 2010, 2013, 2014). NBS Spec. Publ. 260-66 (October 1979). PB80104961**

Velapoldi, R.A., Paule, R.C., Schaffer, R., et al., Standard Reference Materials: A Reference Method for the Determination of Chloride in Serum, NBS Spec. Publ. 260-67 (November 1979). PB80110117**

Mavrodineanu, R., and Baldwin, J.R., Standard Reference Materials: Metal-On-Quartz Filters as a SRM for Spectrophotometry SRM 2031, NBS Spec. Publ. 260-68 (April 1980). PB80197486**

Velapoldi, R.A., Paule, R.C., Schaffer, R., et al., Standard Reference Materials: A Reference Method for the Determination of Lithium in Serum, NBS Spec. Publ. 260-69 (July 1980). PB80209117**

Marinenko, R.B., Biancaniello, F., Boyer, P.A., et al., Standard Reference Materials: Preparation and Characterization of an Iron-Chromium-Nickel Alloy for Microanalysis: SRM 479a, NBS Spec. Publ. 260-70 (May 1981). SN003-003-02328-1*

Seward, R.W., and Mavrodineanu, R., Standard Reference Materials: Summary of the Clinical Laboratory Standards Issued by the National Bureau of Standards, NBS Spec. Publ. 260-71 (November 1981). PB82135161**

Reeder, D.J., Coxon, B., Enagonio, D., et al., Standard Reference Materials: SRM 900, Anti-epilepsy Drug Level Assay Standard, NBS Spec. Publ. 260-72 (June 1981). PB81220758

Interrante, C.G., and Hicho, G.E., Standard Reference Materials: A Standard Reference Material Containing Nominally Fifteen Percent Austenite (SRM 486), NBS Spec. Publ. 260-73 (January 1982). PB82215559**

Marinenko, R.B., Standard Reference Materials: Preparation and Characterization of K-411 and K-412 Mineral Glasses for Microanalysis: SRM 470, NBS Spec. Publ. 260-74 (April 1982). PB82221300**

Weidner, V.R., and Hsia, J.J., Standard Reference Materials: Preparation and Calibration of First Surface Aluminum Mirror Specular Reflectance Standards (SRM 2003a), NBS Spec. Publ. 260-75 (May 1982). PB82221367**

Hicho, G.E., and Eaton, E.E., Standard Reference Materials: A Standard Reference Material Containing Nominally Five Percent Austenite (SRM 485a), NBS Spec. Publ. 260-76 (August 1982). PB83115568**

Furukawa, G.T., Riddle, J.L., Bigge, W.G., et al., Standard Reference Materials: Application of Some Metal SRMs as Thermometric Fixed Points, NBS Spec. Publ. 260-77 (August 1982). PB83117325**

Hicho, G.E., and Eaton, E.E., Standard Reference Materials: Standard Reference Material Containing Nominally Thirty Percent Austenite (SRM 487), NBS Spec. Publ. 260-78 (September 1982). PB83115576**

Richmond, J.C., Hsia, J.J., Weidner, V.R., et al., Standard Reference Materials: Second Surface Mirror Standards of Specular Spectral Reflectance (SRMs 2023, 2024, 2025), NBS Spec. Publ. 260-79 (October 1982). PB84203447**

Schaffer, R., Mandel, J., Sun, T., et al., Standard Reference Materials: Evaluation by an ID/MS Method of the AACC Reference Method for Serum Glucose, NBS Spec. Publ. 260-80 (October 1982). PB84216894**

Burke, R.W., and Mavrodineanu, R., Standard Reference Materials: Accuracy in Analytical Spectrophotometry, NBS Spec. Publ. 260-81 (April 1983). PB83214536**

Weidner, V.R., Standard Reference Materials: White Opal Glass Diffuse Spectral Reflectance Standards for the Visible Spectrum (SRMs 2015 and 2016), NBS Spec. Publ. 260-82 (April 1983). PB83220723**

Bowers, G.N., Jr., Alvarez, R., Cali, J.P., et al., Standard Reference Materials: The Measurement of the Catalytic (Activity) Concentration of Seven Enzymes in NBS Human Serum (SRM 909), NBS Spec. Publ. 260-83 (June 1983). PB83239509**

Gills, T.E., Seward, R.W., Collins, R.J., et al., Standard Reference Materials: Sampling, Materials Handling, Processing, and Packaging of NBS Sulfur in Coal SRMs 2682, 2683, 2684, and 2685, NBS Spec. Publ. 260-84 (August 1983). PB84109552**

Swyt, D.A., Standard Reference Materials: A Look at Techniques for the Dimensional Calibration of Standard Microscopic Particles, NBS Spec.Publ. 260-85 (September 1983). PB84112648**

Hicho, G.E., and Eaton, E.E., Standard Reference Materials: A SRM Containing Two and One-Half Percent Austenite, SRM 488, NBS Spec. Publ. 260-86 (December 1983). PB84143296**

Mangum, B.W., Standard Reference Materials: SRM 1969: Rubidium Triple-Point - A Temperature Reference Standard Near 39.30° C, NBS Spec. Publ. 260-87 (December 1983). PB84149996**

Gladney, E.S., Burns, C.E., Perrin, D.R., et al., Standard Reference Materials: 1982 Compilation of Elemental Concentration Data for NBS Biological, Geological, and Environmental Standard Reference Materials, NBS Spec.Publ. 260-88 (March 1984). PB84218338**

Hust, J.G., Standard Reference Materials: A Fine-Grained, Isotropic Graphite for Use as NBS Thermophysical Property RMs from 5 to 2500 K, NBS Spec. Publ. 260-89 (September 1984). PB85112886**

Hust, J.G., and Lankford, A.B., Standard Reference Materials: Update of Thermal Conductivity and Electrical Resistivity of Electrolytic Iron, Tungsten, and Stainless Steel, NBS Spec.Publ. 260-90 (September 1984). PB85115814**

Goodrich, L.F., Vecchia, D.F., Pittman, E.S., et al., Standard Reference Materials: Critical Current Measurements on an NbTi Superconducting Wire SRM, NBS Spec. Publ. 260-91 (September 1984). PB85118594**

Carpenter, B.S., Standard Reference Materials: Calibrated Glass Standards for Fission Track Use (Supplement to NBS Spec. Publ. 260-49), NBS Spec. Publ. 260-92 (September 1984). PB85113025**

Ehrstein, J.R., Standard Reference Materials: Preparation and Certification of SRM for Calibration of Spreading Resistance Probes, NBS Spec. Publ. 260-93 (January 1985). PB85177921**

Gills, T.E., Koch, W.F., Stolz, J.W., et al., Standard Reference Materials: Methods and Procedures Used at the National Bureau of Standards to Certify Sulfur in Coal SRMs for Sulfur Content, Calorific Value, Ash Content, NBS Spec. Publ. 260-94 (December 1984). PB85165900**

Mulholland, G.W., Hartman, A.W., Hembree, G.G., et al., Standard Reference Materials: Development of a 1mm Diameter Particle Size Standard, SRM 1690, NBS Spec. Publ. 260-95 (May 1985). PB95-232518/AS**

Carpenter, B.S., Gramlich, J.W., Greenberg, R.R., et al., Standard Reference Materials: Uranium-235 Isotopic Abundance Standard Reference Materials for Gamma Spectrometry Measurements, NBS Spec. Publ. 260-96 (September 1986). PB87108544**

Mavrodineanu, R., and Gills, T.E., Standard Reference Materials: Summary of the Coal, Ore, Mineral, Rock, and Refactory Standards Issued by the National Bureau of Standards, NBS Spec. Publ. 260-97 (September 1985). PB86110830**

Hust, J.G., Standard Reference Materials: Glass Fiberboard SRM for Thermal Resistance, NBS Spec. Publ. 260-98 (August 1985). SN003-003-02674-3*

Callanan, J.E., Sullivan, S.A., and Vecchia, D.F., Standard Reference Materials: Feasibility Study for the Development of Standards Using Differential Scanning Calorimetry, NBS Spec. Publ. 260-99 (August 1985). PB86106747**

Taylor, J.K., Trahey, N.M., ed., Standard Reference Materials: Handbook for SRM Users, NBS Spec. Publ. 260-100 (February 1993). PB93183796**

Mangum, B.W., Standard Reference Materials: SRM 1970, Succinonitrile Triple-Point Standard: A Temperature Reference Standard Near 58.08° C, NBS Spec. Publ. 260-101 (March 1986). PB86197100**

Weidner, V.R., Mavrodineanu, R., Mielenz, K.D., et al., Standard Reference Materials: Holmium Oxide Solution Wavelength Standard from 240 to 640 nm - SRM 2034, NBS Spec. Publ. 260-102 (July 1986). PB86245727**

Hust, J.G., Standard Reference Materials: Glass Fiberblanket SRM for Thermal Resistance, NBS Spec. Publ. 260-103 (September 1985). PB86109949**

Mavrodineanu, R., and Alvarez, R., Standard Reference Materials: Summary of the Biological and Botanical Standards Issued by the National Bureau of Standards, NBS Spec. Publ. 260-104 (November 1985). PB86155561**

Mavrodineanu, R., and Rasberry, S.D., Standard Reference Materials: Summary of the Environmental Research, Analysis, and Control Standards Issued by the National Bureau of Standards, NBS Spec. Publ. 260-105 (March 1986). PB86204005**

Koch, W.F., ed., Standard Reference Materials: Methods and Procedures Used at the National Bureau of Standards to Prepare, Analyze, and Certify SRM 2694, Simulated Rainwater, and Recommendations for Use, NBS Spec. Publ. 260-106 (July 1986). PB86247483**

Hartman, A.W., and McKenzie, R.L., Standard Reference Materials: SRM 1965, Microsphere Slide (10 µm Polystyrene Spheres), NIST Spec. Publ. 260-107 (November 1988). PB89153704**

Mavrodineanu, R., and Gills, T.E., Standard Reference Materials: Summary of Gas Cylinder and Permeation Tube Standard Reference Materials Issued by the National Bureau of Standards, NBS Spec. Publ. 260-108 (May 1987). PB87209953**

Candela, G.A., Chandler-Horowitz, D., Novotny, D.B., et al., Standard Reference Materials: Preparation and Certification of an Ellipsometrically Derived Thickness and Refractive Index Standard of a Silicon Dioxide Film (SRM 2530), NIST Spec. Publ. 260-109 (October 1988). PB89133573**

Kirby, R.K., and Kanare, H.M., Standard Reference Materials: Portland Cement Chemical Composition Standards (Blending, Packaging, and Testing), NBS Spec. Publ. 260-110 (February 1988). PB88193347**

Gladney, E.S., O'Malley, B.T., Roelandts, I., et al., Standard Reference Materials: Compilation of Elemental Concentration Data for NBS Clinical, Biological, Geological, and Environmental Standard Reference Materials, NBS Spec.Publ. 260-111 (November 1987). PB88156708**

Marinenko, R.B., Blackburn, D.H., and Bodkin, J.B., Standard Reference Materials: Glasses for Microanalysis: SRMs 1871-1875, NIST Spec. Publ. 260-112 (February 1990). PB90215807**

Mangum, B.W., and Wise, J.A., Standard Reference Materials: Description and Use of a Precision Thermometer for the Clinical Laboratory, SRM 934, NIST Spec. Publ. 260-113 (June 1990). PB90257643**

Vezzetti, C.F., Varner, R.N., and Potzick, J.E., Standard Reference Materials: BrightChromium Linewidth Standard, SRM 476, for Calibration of Optical Microscope Linewidth Measuring Systems, NIST Spec. Publ. 260-114 (January 1991). PB91167163**

Williamson, M.P., Willman, N.E., and Grubb, D.S., Standard Reference Materials: Calibration of NIST SRM 3201 for 0.5 in. (12.65 mm) Serial Serpentine Magnetic Tape Cartridge, NIST Spec. Publ. 260-115 (February 1991). PB91187542**

Mavrodineanu, R., Burke, R.W., Baldwin, J.R., et al., Standard Reference Materials: Glass Filters as a Standard Reference Material for Spectrophotometry-Selection, Preparation, Certification and Use of SRM 930 and SRM 1930, NIST Spec. Publ. 260-116 (March 1994). PB94-188844/AS**

Vezzetti, C.F., Varner, R.N., and Potzick, J.E., Standard Reference Materials: Anti-reflecting-Chromium Linewidth Standard, SRM 475, for Calibration of Optical Microscope Linewidth Measuring Systems, NIST Spec.Publ. 260-117 (January 1992). PB92-149798**

Williamson, M.P., Standard Reference Materials: Calibration of NIST Standard Reference Material 3202 for 18-Track, Parallel, and 36-Track, Parallel Serpentine, 12.65 mm (0.5 in), 1491 cpmm (37871 cpi), Magnetic Tape Cartridge, NIST Spec. Publ. 260-118 (July 1992). PB92-226281**

Vezzetti, C.F., Varner, R.N., and Potzick, Standard Reference Materials: Antireflecting-Chromium Linewidth Standard, SRM 473, for Calibration of Optical Microscope Linewidth Measuring System, NIST Spec. Publ. 260-119 (September 1992)

Caskey, G.W., Philips, S.D., Borchardt., et al., Standard Reference Materials: A Users' Guide to NIST SRM 2084: CMM Probe Performance Standard, NIST Spec. Publ. 260-120 (1994)

Rennex, B.G., Standard Reference Materials: Certification of a Standard Reference Material for the Determination of Interstitial Oxygen Concentration in Semiconductor Silicon by Infrared Spectrophotometry, NIST Spec.Publ. 260-121 (1994) PB95-125076/AS

Gupta, D., Wang, L., Hanssen, L.M., Hsai, J.J., and Datla, R.U., Polystyrene Films for Calibrating the Wavelength Scale of Infrared Spectrophotometer (SRM 1921). NIST Spec. Publ. 260-122 (1995) PB95-226866/AS

Development of Technology and the Manufacture of Spectrometric SRMs for Naval Brasses (MC62 M63). NIST Spec. Publ. 260-123 (IN PREP).

Strouse, G.F., SRM 1744: Aluminum Freezing Point Standard. NIST Spec. Publ. 260-124 (1995) SN003-003-03342-1

Schiller, S.B, Standard Reference Materials: Statistical Aspects of the Certification of Chemical Batch SRMs. NIST Spec. Publ. 260-125 (1996) PB96-210877/AS

Guenther, F.R., Dorko, W.D., Miller, W.R., et al., Standard Reference Materials: The NIST Traceable Reference Material Program for Gas Standards, NIST Spec. Publ. 260-126 (1996) PB96-210786/AS

Strouse, G.F., and Ahmet, A.T., Standard Reference Material 1747: Tin Freezing-Point Cell and Standard Reference Material 1748: Zinc Freezing-Point Cell. NIST Spec. Publ. 260-127 SN003-003-03488-6.

Zhang, Z.M., Gentile, T.R., Migdall, A.L., and Datla, R.U., Transmission Filters with Measured Optical Density at 1064 nm Wavelength--SRMs 2046, 2047, 2048, 2049, 2050, and 2051. SRM Spec. Publ. 260-128 (IN PREP).

Potzick, J.E., Antireflecting-Chromium Linewidth Standard, Standard Reference Material 473, for Calibration of Optical MicroscopeLinewidth Measuring Systems, NIST Spec. Publ. 260-129 (1997) SN003-003-03447-9.

Zarr, R.R., Standard Reference Materials: Glass Fiberboard, Standard Reference Material 1450c, for Thermal Resistance from 280K to 340K, NIST Spec. Publ. 260-130 (1997) PB97-177166/AS.

Ehrstein, J.R., and Croarkin, M.C., The Certification of 100 mm Diameter Silicon Resistivity SRMs 2541 through 2547 Using Dual-Configuration Four-Point Probe Measurements. NIST Spec. Publ. 260-131.

Strouse, G.G., Standard Reference Material 1745: Indium Freezing Point Standard and Standard Reference Material 2232: Indium DSC Melting Point Standard, NIST Spec. Publ. 260-132 (IN PREP).

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Standard Reference Materials:
Acetylene $^{12}C_2H_2$ Absorption Reference for 1510–1540 nm Wavelength Calibration – SRM 2517

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ABSTRACT

Standard Reference Material (SRM) 2517 is an optical-fiber-coupled absorption cell containing acetylene ($^{12}C_2H_2$) gas. It is intended for use in calibrating the wavelength scale of wavelength measuring instruments in the 1500 nm region. About 50 accurately measured absorption lines of the R and P branch of the $\nu_1 + \nu_3$ rotational-vibrational band of $^{12}C_2H_2$ are located between 1510-1540 nm. We have measured the pressure-induced shift of the lines and certify the SRM wavelengths with an expanded uncertainty (coverage factor $k = 2$) of ± 0.0006 nm. This publication describes the SRM, the NIST measurement procedure, and the uncertainty determination for SRM certification.

Keywords: absorption; acetylene; molecular spectroscopy; optical fiber communication; Standard Reference Material; wavelength calibration; wavelength division multiplexing; wavelength reference; WDM

1. Introduction

Wavelength references are needed in the 1500 nm region to support future wavelength division multiplexed (WDM) optical fiber communication systems. In a WDM system, many wavelength channels are sent down the same fiber, thereby increasing the bandwidth of the system by the number of channels. If one channel's wavelength were to shift, crosstalk could occur between it and a neighboring channel. Wavelength references are needed to calibrate instruments that measure and set the wavelengths of the channels.

The NIST Optoelectronics Division has received numerous inquiries about wavelength calibration in the 1500 nm region. Most applications involve calibrating a commercial optical spectrum analyzer (OSA) which is based on the dispersion of light by a diffraction grating. An OSA typically has a resolution of 0.1 nm; the highest resolution currently available is 0.05 nm. Most users are interested in calibrating these instruments to an uncertainty between 0.1 and 0.01 nm. Many users are also interested in calibrating the wavelength scan linearity of their instruments. A calibration service did not seem practical for these instruments; they are large and fragile, and the optical elements can shift during shipment, causing a loss of wavelength calibration. The NIST solution is to produce Standard Reference Material (SRM) cells containing gases which have accurately measured absorption lines in this wavelength region. Fundamental molecular absorptions provide references which are very stable under changing environmental conditions such as temperature and pressure variations, or the presence of electric and magnetic fields. These SRMs can also be used to calibrate the wavelength readout of tunable lasers and check the accuracy of wavelength meters.

There are very few wavelength references available in the 1500 nm region. There is only one gas laser reference line: the 1523 nm helium-neon laser. The only atomic absorption lines in this region are between excited states and thus require initial excitation by a laser or electric discharge. Another possibility is frequency doubling 1500–1560 nm light to probe atomic transitions in the 750–780 nm region. This requires fairly complicated and expensive apparatus. Molecular transitions in the 1500 nm region are combination or overtone bands that can be probed directly.

We have chosen to use the absorption lines of acetylene (this SRM) and hydrogen cyanide (SRM 2519) for references in the 1500 nm region for the following reasons:

(1) Molecular lines are simple to access, since this involves simply passing light through a cell containing the gas and observing the absorption spectrum.

(2) These molecules have strong absorption bands in this region.

(3) The combined spectra of the two gases cover the communications band, from 1510 to 1565 nm.

(4) The spectra are uncomplicated; thus it is not difficult to identify the lines.

(5) The wavelengths of the prominent lines have been measured with an uncertainty of less than 0.001 nm.

(6) There are many reference lines with spacings ranging from 0.4 to 0.9 nm, providing for scan linearity calibration as well as single-point wavelength calibration.

(7) A cell containing the gas can be easily pigtailed with optical fiber, so that it is compatible with the sources and measurement instruments used by the optical fiber communications industry.

(8) The gas cell design allows for versatile calibration capability; it can be used with a variety of sources (LED, amplified spontaneous emission, white light, laser, etc.) to calibrate any wavelength measuring instrument in this region.

2. SRM 2517 description

This SRM is based on the fundamental absorptions of light by acetylene ($^{12}C_2H_2$). The spectrum of this molecule in the 1500 nm region is shown in Fig. 1. The lines are the R and P branches of the $\nu_1 + \nu_3$ rotational-vibrational band of $^{12}C_2H_2$. Figure 2 shows a schematic diagram of our apparatus for measuring the spectrum in Fig. 1. Light from an LED source (about 80 nm bandwidth) is coupled to an acetylene absorption cell using single-mode optical fiber. The light exiting the fiber is collimated by a lens, passes through the absorption cell, and is coupled into another section of single-mode fiber. This fiber is connected to a commercial optical spectrum analyzer. The resulting spectrum is the emission spectrum from the LED with narrow depressions due to the absorption of the light by the molecules. The spectrum in Fig. 1 has been normalized to the LED spectrum. We have also recorded the spectrum using a tunable laser as the light source. In this case the transmission through the cell was monitored by a detector as the laser's wavelength was tuned.

The vacuum wavelengths of the acetylene $\nu_1 + \nu_3$ lines have been measured with an uncertainty of less than 0.0001 nm [1]. Table 1 lists the literature values for the wavelengths from 1513 to 1541 nm. We have compared these values with other experimental measurements in the literature [2,3] and find agreement within 0.0002 nm, which is within the expanded uncertainty of Refs. 2 and 3. Our measurements of six lines (below) also agree within our 0.0015 nm wavelength meter uncertainty.

3. SRM design

The SRM design is essentially that shown schematically in Fig. 2; an absorption cell is pigtailed with single-mode optical fiber. The input and output ports are FC/PC fiber bulkhead connectors on the outside of the instrument box. Users supply their own light source and detection; this enables flexibility since some users may want to calibrate optical spectrum analyzers using a broadband light source, and others may want to check the calibration of tunable lasers or wavelength meters using a narrowband source.

The absorption cell material is Pyrex glass; the windows are fused to the cell. The cell is first evacuated and leak-checked, and then filled with high purity gas (99.96% $^{12}C_2H_2$). It is then tipped off using a torch, providing an all-glass seal. The cell is securely mounted in an aluminum holder. The fiber-coupled collimators are also mounted on this holder using commercially available aligners. FC/PC connectors on the other ends of the optical fibers connect to bulkhead connectors mounted on the instrument box which houses the cell holder.

We chose a pressure of 27 kPa (200 Torr) so that the lines would be pressure-broadened by less than 0.05 nm and thus provide a large signal, without significant loss of resolution, when used with instruments with this resolution. At this pressure, a slight shift of each line (pressure shift) is possible due to energy level shifts caused by the interaction of the molecules during elastic collisions [4]. An upper limit for the pressure shift of 200 kHz/Torr (1.5 kHz/Pa) has been reported for one acetylene line at low pressure [5]. We have measured the pressure shift of several lines, as described in section 4.1.

4. Line center uncertainty

For this Standard Reference Material, the stability of the wavelength of each absorption line is a critical characteristic. The choice of fundamental molecular absorption lines makes the SRM insensitive to most changes in environmental conditions. The symmetric isotopic species of acetylene ($^{12}C_2H_2$ and $^{13}C_2H_2$) are particularly insensitive to changes because they have no permanent dipole moment. Thus, pressure broadening, pressure shift, and Stark shift are expected to be small. For the desired SRM certification uncertainty of about 0.001 nm, the only line shift mechanism which could potentially contribute at this level is the shift due to pressure (collisions between molecules). Other factors associated with line fitting could cause apparent shifts of lines. In section 4.1 we discuss our measurement of the pressure shift.

4.1 Pressure shift measurement

A schematic diagram of our pressure shift measurement apparatus in shown in Fig. 3. Light from a tunable diode laser is sent through two absorption cells simultaneously, and the transmission through each cell is monitored by a detector. One cell contains acetylene gas at low pressure (8.0 ± 0.8 kPa; about 60 Torr) and the other contains a relatively high pressure of 54 ± 5 kPa (about 400 Torr). The pressure uncertainty quoted is the expanded uncertainty using a coverage factor $k = 2$. A wavelength meter with an uncertainty of 1 part in 10^6 (0.0015 nm) monitors the wavelength of the laser. A computer scans the wavelength of the laser in approximately 0.001 nm steps and records the two detectors and wavelength meter readings.

Figure 4 shows the spectrum obtained of line P5. The pressure broadening in the high-pressure cell is obvious. We are interested in the relative shift between the line centers in the low-pressure and high-pressure cells. Six lines were recorded using this technique. The measured quantity, the transmitted power I_T, is related to the absorption coefficient α and the absorption path length L by

$$I_T = I_o \exp(-\alpha L), \qquad (1)$$

where I_o is the incident power. We first normalized the data to I_o and then took the natural logarithm to obtain αL. The low pressure lines were fitted to a Voigt profile [6] using the least-squares method of a commercial fitting program. Due to the dominance of pressure broadening in the high pressure cell, these lines were fitted to a Lorentzian profile. Several factors complicated the fitting procedure: overlap with nearby lines, background slopes, interference fringes on the cell transmission spectra, and uncertainty in the wavelength of each point. Our approach to minimizing and measuring the effects of these contributions is discussed below.

4.1.1 Overlap with nearby lines

Wings of nearby lines can skew the shape of the line being measured and shift its apparent center. There are a number of weak lines throughout the spectrum which are due to hot bands (transitions that are not out of the ground vibrational state) [7]. To account for the weak nearby lines, we did a multiple-line fit to the low pressure cell spectrum (Fig. 5a – spectrum inverted) and then used the line locations and strengths obtained in this fit as input to a multiple-line fit of the high pressure cell spectrum (Fig. 5b). A multiple-line fit is simply a fit to a sum of lines instead of a single line. For the spectra shown in Figs. 5a and 5b, the multiple-line fit consisted of the main line near 1528.6 nm and three weak lines at longer wavelengths. After modeling the weak lines, we subtracted them from the data to obtain a spectrum that contained only the main line. This modified spectrum could then be fit more accurately with the appropriate error bars. We estimated the uncertainty in this process by visibly changing the center wavelength parameter of the nearest line and refitting the data with this parameter fixed. This resulted in a negligible shift of the main line for the low pressure cell data and a maximum shift of ± 0.0002 nm for the high pressure cell data. Assuming a rectangular distribution with upper and lower limits of ± 0.0002 nm about the mean value, this corresponds to a standard uncertainty (estimated standard deviation) u of 0.0001 nm (=0.0002/√3).

4.1.2 Background slope

A background slope on the spectrum can shift the apparent center of a line, particularly for the wide lines of the high pressure cell. We have identified two sources of background slope: (1) wavelength dependence of the fiber couplers and other optical components, and (2) change in the laser power. Since the magnitudes of the background slopes were small, we chose to fit the data without removing the slopes. Slight residual slopes in the data could be seen in the fit residual plots. By fitting the data again with the slope removed, we calculate that the maximum shift due to any residual slope is negligible for the low pressure cell data and ± 0.0002 nm for the high pressure cell data. Assuming a rectangular distribution with upper and lower limits of ± 0.0002 nm about the mean value, this corresponds to a standard uncertainty u of 0.0001 nm.

4.1.3 Interference fringes

Interference fringes due to reflections of the laser light can be a problem. We spent considerable time reducing these effects. The windows of the cells were mounted at a 10° angle with respect to the laser beam path. We selected low back-reflection fiber-pigtailed lenses and terminated the fibers (at the detectors) with angled fiber connectors. These measures reduced the interference fringe amplitude considerably. The amplitudes of the remaining fringes were less than 0.2%. We modeled the effect of the fringes by simulating lines with and without the modulation and fitting the simulated data to obtain the line centers. Using the worst-case scenario for the phase of the modulation relative to the line center, we calculate a maximum apparent line shift of ± 0.00001 nm for the low pressure cell data and ± 0.0004 nm for the high pressure cell data. Assuming a rectangular distribution with upper and lower limits of ± 0.0004 nm about the mean value, this corresponds to a standard uncertainty u of 0.0002 nm for the high pressure cell data.

4.1.4 Wavelength uncertainty

Since the transmissions through the low and high pressure cells were measured simultaneously, the accuracy of the wavelength meter was adequate for this measurement. However, its limited resolution (0.001 nm) did add noise to the data. This, in turn, complicated the fitting since there was noise in both y (transmitted intensity) and x (wavelength), and our fitting program could accommodate uncertainty in y only. Since the transmission is a complicated function of wavelength, uncertainty of the wavelength has the largest effect where the transmission slope is the greatest. Our approach to estimating the uncertainty in each data point was to first fit the data with a Lorentzian lineshape [8]. We then took the derivative of this function with respect to wavelength and from that derived a virtual uncertainty in the transmission T due to this wavelength dependence:

$$\delta T_\lambda \approx \left| \partial T / \partial \lambda \right| \delta \lambda \,. \qquad (2)$$

We then combined this uncertainty with the uncertainty due to intensity variation (measured experimentally) for the overall estimate of uncertainty for each transmission measurement point.

5. Uncertainty determination

We measured the pressure shifts for six different lines, choosing lines at a variety of locations in the spectrum. This ensured that our data would be sensitive to any variations in the pressure shift, if the shift varied with line number. We obtained reduced residual-sum-of-squares (χ^2) values ranging from 0.9 to 2.6 for the fitting of six lines. From the fit residual plots, we could discern the slight slopes and sinusoidal modulation described above; fitting and removing these slopes and modulations reduced the χ^2 values to 0.8 - 1.1. As discussed above, we used the line center values obtained from fitting without the slopes and modulations removed, since we do not think it was justified to arbitrarily remove these effects. Instead, we used the residual plots to estimate the uncertainty in the line centers. The magnitudes of the slopes and modulations in the residual plots were consistent with background data taken with the cells removed from the measurement apparatus.

The uncertainty budget for the relative line center determinations is given in Table 2 and the uncertainty source type [9] (A or B) is indicated. The largest source of uncertainty is the apparent shift due to interference fringes. Table 3 lists the shifts measured for six lines. Since it is possible that the pressure shifts for the different lines are slightly different, we use the average of the pressure shifts measured, and combine the individual shift standard uncertainty $u_c(\Delta)$ with the standard deviation of the six line shifts $u(six)$ using the a root-sum-of-squares (RSS) method to obtain the overall line shift standard uncertainty of 0.0005 nm.

Unless otherwise stated, the uncertainties given below are all expanded uncertainties using a coverage factor $k = 2$. Our result is a pressure shift of 0.0015 ± 0.0010 nm for a pressure difference of 46 ± 5 kPa (345 ± 40 Torr); yielding $(+3.2 \pm 2.2) \times 10^{-5}$ nm/kPa [$(+4.3 \pm 2.9) \times 10^{-6}$ nm/Torr], or -4.1 ± 2.8 MHz/kPa (-0.55 ± 0.37 MHz/Torr).

For the 27 $\pm$ 7 kPa (200 $\pm$ 50 Torr) pressure used in the SRM units, the pressure shift is + 0.0009 $\pm$ 0.0006 nm. Table 4 lists the certified wavelengths for the SRM units. We obtain these wavelengths by adding the pressure shift to the literature values given in Table 1.

6. SRM 2517 certificate

The certificate for SRM 2517 is presented in Appendix A. It includes the certified wavelength values for the $\nu_1 + \nu_3$ band of $^{12}C_2H_2$ ranging from R25 to P25 (1513-1541 nm), a scan of the band, and instructions for storage, handling, and use of the SRM.

7. Acknowledgment

The authors gratefully acknowledge the help of C. Wang for useful discussions and suggestions on uncertainty analysis, D. Franzen and R. Fox for careful reading of the SRM documentation, and R. Gettings for coordinating the certification and issuance of SRM 2517.

8. References

[1] K. Nakagawa, M. de Labachelerie, Y. Awaji, and M. Kourogi, "Accurate optical frequency atlas of the 1.5-μm bands of acetylene," J. Opt. Soc. Am. B **13**, 2708-2714 (1996).

[2] T. Yoshida and H. Sasada, "Near-infrared spectroscopy with a wavemeter," J. Molec. Spectrosc. **153**, 208-210 (1992).

[3] G. Guelachvili and K. N. Rao, Handbook of Infrared Standards II (Academic Press, San Diego, CA, 1993), pp. 564-568.

[4] Demtröder, *Laser Spectroscopy*, second edition (Springer-Verlag Berlin Heidelberg New York 1996), pp. 71-82.

[5] Y. Sakai, S. Sudo, and T. Ikegami, "Frequency Stabilization of Laser Diodes Using 1.51 – 1.55 μm Absorption Lines of $^{12}C_2H_2$ and $^{13}C_2H_2$," IEEE J. Quantum Electron. **28**, 75-81 (1992).

[6] A Voigt profile is a convolution of Lorentzian and Gaussian profiles; it results when there is a combination of Gaussian broadening (due to Doppler broadening, for example) and Lorentzian line shape (due to natural linewidth or collision line broadening, for example). See W. Demtröder, *Laser Spectroscopy*, second edition (Springer-Verlag Berlin Heidelberg New York 1996), pp. 70-71.

[7] A. Baldacci, S. Ghersetti, and K.N. Rao, "Interpretation of the Acetylene Spectrum at 1.5 μm," J. Mol. Spectrosc. **68**, 183-194 (1977).

[8] Due to the complexity of a Voigt profile, a Lorentzian profile was used to estimate the virtual uncertainty in transmission caused by wavelength uncertainty. A Lorentzian profile is a reasonable approximation to the lineshape; the lines are predominantly Lorentzian due to pressure broadening.

[9] B. N. Taylor and C. E. Kuyatt, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," Natl. Inst. Stand. Technol. Tech. Note 1297 (Jan. 1993).

Table 1. Vacuum Wavelengths of Acetylene $^{12}C_2H_2$ Lines

The wavelengths were calculated using the experimentally determined molecular constants from Ref. 1, and were compared with less accurate measurements (Refs. 2 and 3). The wavelength uncertainty estimate given in Ref. 1 is 1×10^{-6} nm (one standard uncertainty).

R Branch	wavelength (nm)	P Branch	wavelength (nm)
25	1513.1999	1	1525.7598
24	1513.5830	2	1526.3138
23	1513.9725	3	1526.8742
22	1514.3682	4	1527.4410
21	1514.7702	5	1528.0142
20	1515.1785	6	1528.5938
19	1515.5930	7	1529.1798
18	1516.0139	8	1529.7722
17	1516.4411	9	1530.3710
16	1516.8746	10	1530.9762
15	1517.3144	11	1531.5878
14	1517.7605	12	1532.2059
13	1518.2129	13	1532.8303
12	1518.6716	14	1533.4613
11	1519.1367	15	1534.0986
10	1519.6081	16	1534.7424
9	1520.0858	17	1535.3927
8	1520.5699	18	1536.0493
7	1521.0603	19	1536.7125
6	1521.5570	20	1537.3821
5	1522.0601	21	1538.0582
4	1522.5696	22	1538.7407
3	1523.0854	23	1539.4298
2	1523.6075	24	1540.1253
1	1524.1360	25	1540.8273

Table 2. Uncertainty Budget

Uncertainty budget for determination of relative line centers for the low pressure and high pressure cells. The combined standard uncertainties are root-sum-of-squares (RSS) of the standard uncertainties due to the sources listed. The absolute accuracy of the wavelength meter is not included since we are concerned only with the relative line centers.

Source of uncertainty	Uncertainty type [9]	Standard uncertainty (nm) 8 kPa *(low)* cell	Standard uncertainty (nm) 54 kPa *(high)* cell
Nearby line contribution	B	< 0.00001	0.0001
Background slope	B	< 0.00001	0.0001
Interference fringes	B	< 0.00001	0.0002
Fit statistical uncertainty	A	0.0001	0.0001
Combined standard uncertainty		$u_c(low) = 0.0001$	$u_c(high) = 0.0003$

Table 3. Pressure Shift Measurement

Measured center wavelengths and shifts for six lines of $^{12}C_2H_2$. The individual line shift standard uncertainty $u_c(\Delta)$ is the RSS combined uncertainty of $u_c(low)$ and $u_c(high)$ from Table 2. The lines in the high pressure cell are shifted by an average of + 0.0015 nm relative to the lines in the low pressure cell.

Line	Measured center λ (nm) 8 kPa *(low)* cell	Measured center λ (nm) 54 kPa *(high)* cell	Shift (nm) [$\Delta = high - low$]	Shift standard uncertainty $u_c(\Delta)$ (nm)
R18	1516.0130	1516.0150	+ 0.0020	0.0003
P3	1526.8738	1526.8749	+ 0.0011	0.0003
P5	1528.0136	1528.0154	+ 0.0018	0.0003
P6	1528.5934	1528.5950	+ 0.0016	0.0003
P14	1533.4604	1533.4619	+ 0.0015	0.0003
P25	1540.8270	1540.8278	+ 0.0008	0.0003
		Average shift	+ 0.0015	

Standard deviation of six lines, $u(six)$ 0.0004 nm

Shift overall combined standard uncertainty $[(u(six))^2 + (u_c(\Delta))^2]^{1/2}$ 0.0005 nm

Table 4 Certified Wavelengths for SRM 2517

Literature values from Ref. 1 adjusted for the pressure shift due to the 27 kPa (200 Torr) cell pressure. These vacuum wavelengths of the $\nu_1 + \nu_3$ band $^{12}C_2H_2$ are certified with an expanded uncertainty of ± 0.0006 nm (coverage factor $k = 2$).

R Branch	wavelength (nm)	P Branch	wavelength (nm)
25	1513.2007	1	1525.7607
24	1513.5839	2	1526.3147
23	1513.9733	3	1526.8751
22	1514.3690	4	1527.4419
21	1514.7710	5	1528.0151
20	1515.1793	6	1528.5946
19	1515.5939	7	1529.1806
18	1516.0148	8	1529.7730
17	1516.4419	9	1530.3718
16	1516.8754	10	1530.9770
15	1517.3152	11	1531.5886
14	1517.7613	12	1532.2067
13	1518.2138	13	1532.8312
12	1518.6725	14	1533.4621
11	1519.1376	15	1534.0995
10	1519.6090	16	1534.7433
9	1520.0867	17	1535.3935
8	1520.5707	18	1536.0502
7	1521.0611	19	1536.7134
6	1521.5579	20	1537.3830
5	1522.0610	21	1538.0590
4	1522.5704	22	1538.7416
3	1523.0862	23	1539.4306
2	1523.6084	24	1540.1261
1	1524.1369	25	1540.8281

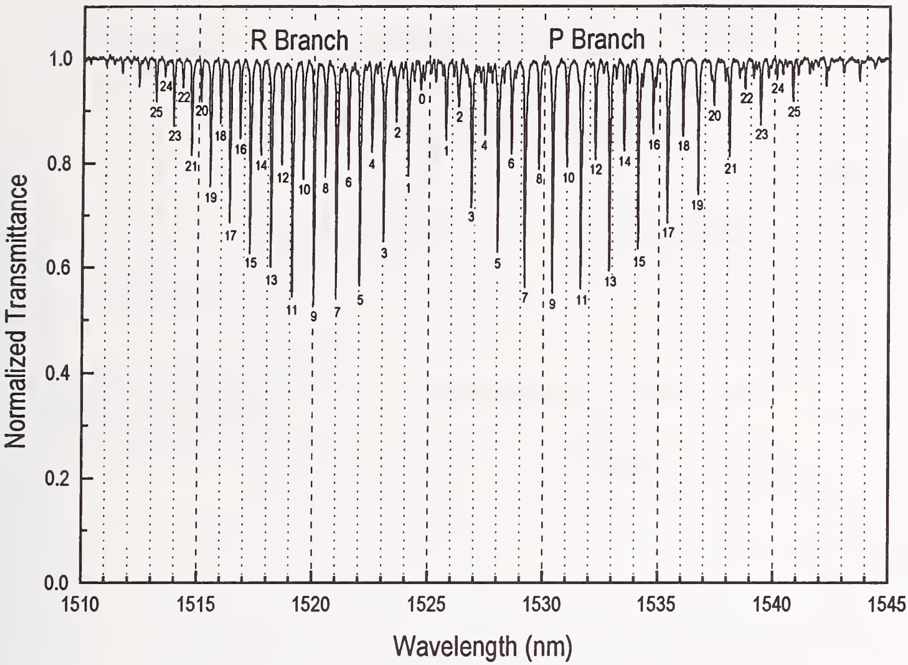


Figure 1. Acetylene ($^{12}C_2H_2$) spectrum taken by passing LED light through an absorption cell and recording the spectrum of the transmitted light using an optical spectrum analyzer with 0.05 nm resolution. This spectrum has been divided by the LED spectrum.

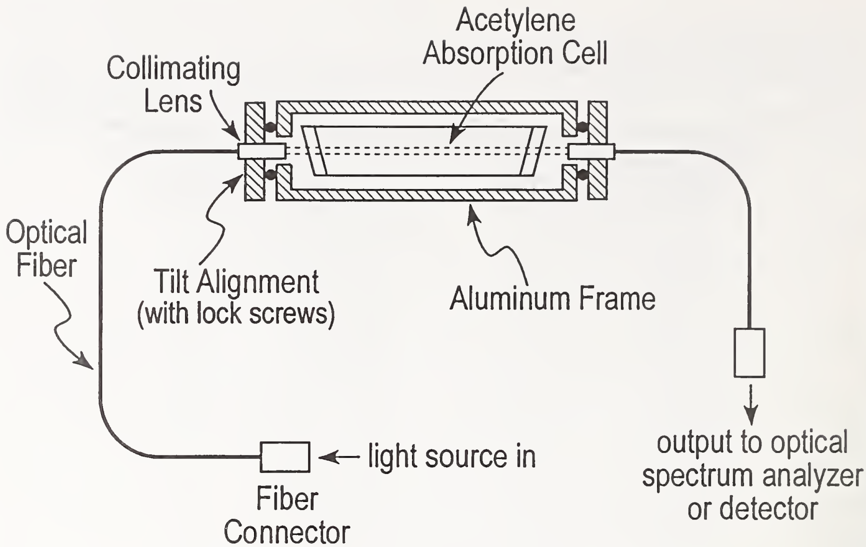


Figure 2. Schematic of fiber-pigtailed cell holder.

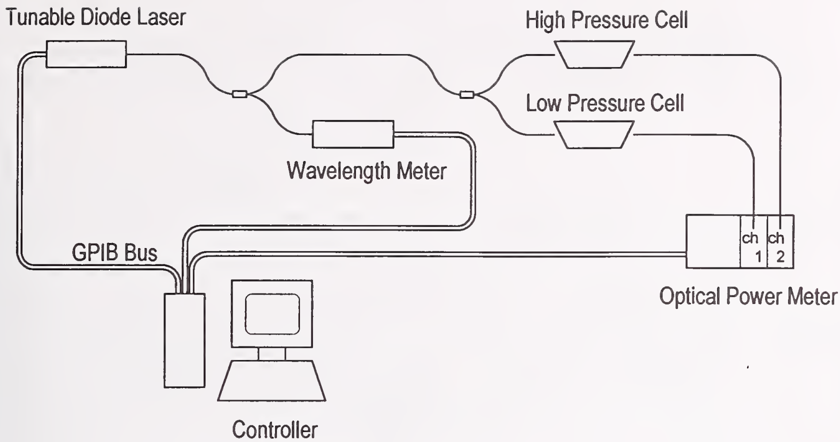


Figure 3. Schematic of the pressure-shift measurement apparatus.

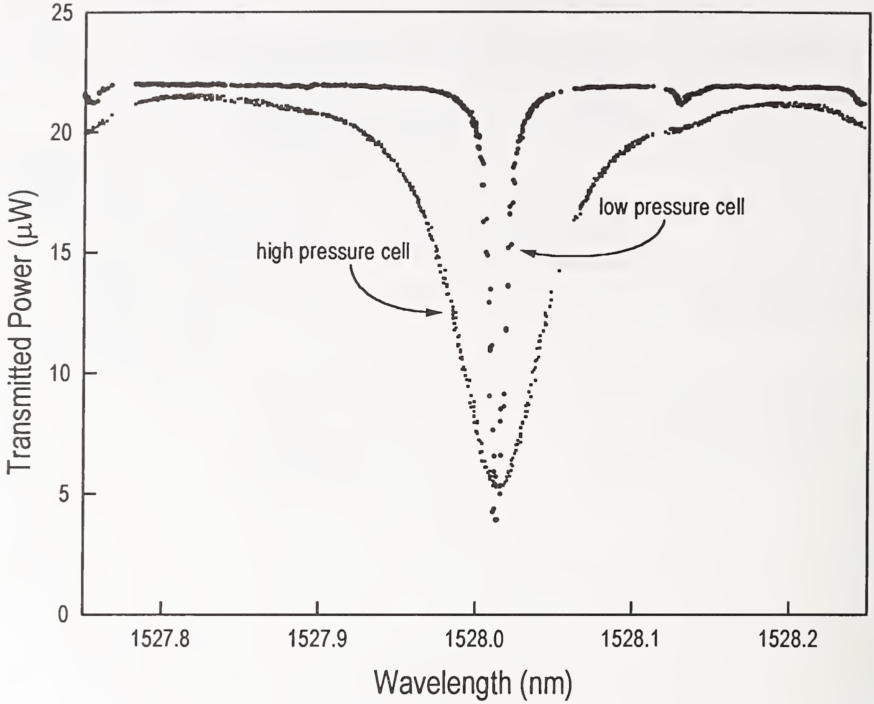
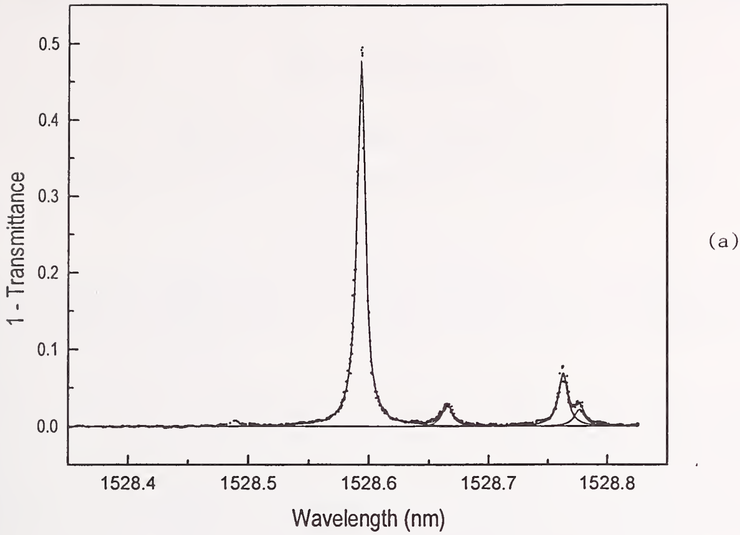


Figure 4. Scan over line P5 showing transmission through low pressure and high pressure cells.



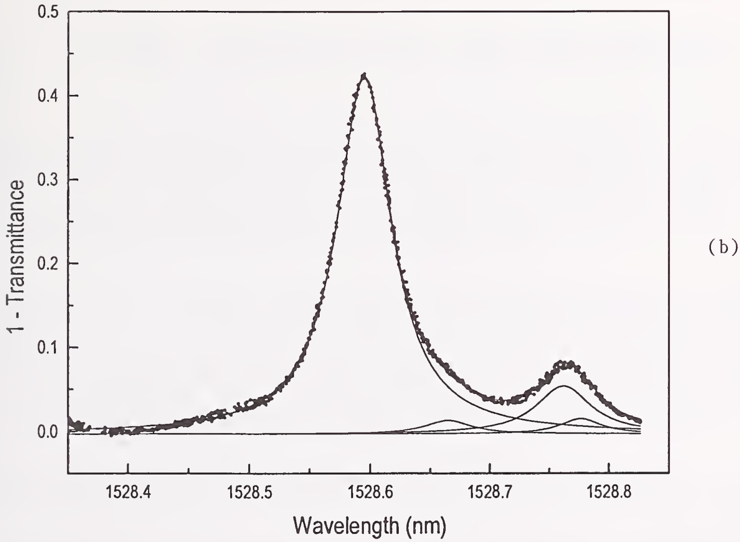


Figure 5. (a) Multiple line fit of line P6, low pressure cell. Of all the lines measured, P6 had the most significant contribution from nearby lines. (b) Multiple line fit of line P6, high pressure cell.

National Institute of Standards & Technology

Certificate

Standard Reference Material® 2517

Wavelength Reference Absorption Cell – Acetylene ($^{12}C_2H_2$)

Serial No.:

This Standard Reference Material (SRM) is intended for use in calibrating the wavelength scale of wavelength measuring equipment in the spectral region from 1513 nm to 1541 nm. SRM 2517 is an optical-fiber-coupled absorption cell containing acetylene ($^{12}C_2H_2$) gas. Acetylene has more than 50 accurately measured absorption lines in the 1500 nm wavelength region.

Certified Wavelength Values: The vacuum wavelengths of absorption lines in the R and P branch of the $\nu_1 + \nu_3$ rotational-vibrational band of $^{12}C_2H_2$ have been measured previously to high accuracy by several independent research groups [1,2]. These literature values for the vacuum wavelengths were adjusted for the pressure shift due to the collisions between acetylene molecules at the 27 kPa (200 Torr) pressure within the SRM cell to obtain the certified wavelength values for this SRM. Details of the measurement procedure and data analysis for the determination of the pressure shift can be found in reference [3]. A spectrum of the absorption band is shown in Figure 1 and certified wavelength values are given in Table 1. Figure 2 shows a higher resolution scan near line P9. The wavelengths of the lines listed in Table 1 are certified with an expanded uncertainty of $\pm$ 0.0006 nm (coverage factor $k = 2$).

Expiration of Certification: The certification of this SRM is indefinite within the measurement uncertainties specified, provided the SRM is handled, stored, and used in accordance with the instructions given in this certificate.

Measurement Conditions and Procedure: The long term stability of acetylene and the use of fundamental molecular absorption lines render the SRM insensitive to changes in environmental conditions. The purpose of the certification procedure is to verify that the unit contains the correct pressure of $^{12}C_2H_2$ gas and has no significant contaminants that produce additional absorption lines. Measurements were made using a 0.05 nm resolution optical spectrum analyzer. Spectra similar to those shown in Figures 1 and 2 were taken of each SRM unit and compared with measurements of reference absorption cells maintained at NIST.

Storage and Handling: The protective caps provided for the FC/PC fiber connectors should be replaced when the SRM is not in use. This SRM is intended to be used in a laboratory environment near ambient room temperature (22 °C $\pm$ 5 °C). Optical alignment is critical; the user should avoid exposing the unit to large temperature variations, temperature cycling, or mechanical shock, as these may cause the optical alignment to degrade. Optical misalignment affects the throughput of the SRM but will not shift the centers of the absorption lines. A more serious, but less likely problem is cell breakage or leakage. The unit should be replaced if the linewidths or depths differ significantly from those shown in Figures 1 and 2 (when measured using comparable resolution).

Development of the SRM and supporting measurements were performed by S.L. Gilbert and W.C. Swann of the NIST Optoelectronics Division.

Gaithersburg, MD 20899
Certificate Issue Date: 20 October 1997

Thomas E. Gills, Chief
Standard Reference Materials Program

Statistical consultation was provided by C.M. Wang of the NIST Statistical Engineering Division.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the Standard Reference Materials Program by R.J. Gettings.

Table 1. Certified Wavelengths for SRM 2517

Literature values from Reference [1] adjusted for the pressure shift due to the 27 kPa (200 Torr) cell pressure. These vacuum wavelengths of the $\nu_1 + \nu_3$ band of $^{12}C_2H_2$ are certified with an expanded uncertainty of $\pm$ 0.0006 nm (coverage factor $k = 2$).

R Branch	nm	P Branch	nm
25	1513.2007	1	1525.7607
24	1513.5839	2	1526.3147
23	1513.9733	3	1526.8751
22	1514.3690	4	1527.4419
21	1514.7710	5	1528.0151
20	1515.1793	6	1528.5946
19	1515.5939	7	1529.1806
18	1516.0148	8	1529.7730
17	1516.4419	9	1530.3718
16	1516.8754	10	1530.9770
15	1517.3152	11	1531.5886
14	1517.7613	12	1532.2067
13	1518.2138	13	1532.8312
12	1518.6725	14	1533.4621
11	1519.1376	15	1534.0995
10	1519.6090	16	1534.7433
9	1520.0867	17	1535.3935
8	1520.5707	18	1536.0502
7	1521.0611	19	1536.7134
6	1521.5579	20	1537.3830
5	1522.0610	21	1538.0590
4	1522.5704	22	1538.7416
3	1523.0862	23	1539.4306
2	1523.6084	24	1540.1261
1	1524.1369	25	1540.8281

INSTRUCTIONS FOR USE

General Considerations: The SRM can be used to calibrate a wavelength measuring instrument in the 1510 nm to 1540 nm region. The wavelength calibration is vacuum wavelength; if the user requires the wavelength in air, the appropriate correction for the index of refraction of air must be applied (see Reference [4]). Depending on what type of instrument is being calibrated, a broadband source or a tunable narrowband source may be used.

Use With a Broadband Source: A broadband source in the 1500 nm region (such as a light emitting diode, white light, or amplified spontaneous emission source) is useful when calibrating a low resolution instrument such as a diffraction grating based optical spectrum analyzer or monochrometer. A schematic for this type of calibration is shown in Figure 3(a). Light from the broadband source is coupled into the SRM and the output (transmission through the SRM) is connected to the instrument that is being calibrated. The absorption lines of acetylene appear as dips in the spectrum of the light source (see Figure 1).

Use With a Narrowband Source: The SRM can be used to calibrate the wavelength scale of a tunable narrowband source in this region (such as a diode laser or fiber laser). Alternatively, a tunable source and the SRM can be used to check the calibration of a wavelength meter, as shown in Figure 3(b). The laser is tuned over one or more of the acetylene absorption lines. The transmission through the SRM is monitored by a detector; the transmitted power passes through a minimum at the center of an absorption line.

Suggested Procedure for Low-Accuracy Requirements; Calibration Uncertainty ≥ 0.1 nm: Connect the light source (either broadband or narrowband, as discussed above) to one of the fiber connectors on the SRM unit using a single-mode optical fiber terminated with a clean FC/PC connector. After identifying the absorption lines by comparing to the spectrum in Figure 1, find the center or the minimum point of a line listed in Table 1. If the instrument has variable resolution, it is best to use a resolution of ≤ 0.2 nm. For this level of accuracy, the procedure used to find the line center can be quite simple: setting a cursor to the line center or minimum by eye is sufficient. If using a tunable source, simply tune it to the transmission minimum of the line, using tuning steps of ≤ 0.01 nm. Calibrate the instrument to the wavelength of this line (from Table 1) using the calibration procedure specified by the instrument manufacturer. The instrument's linearity can be checked by repeating the procedure for a different absorption line and comparing it to the value listed in Table 1.

Suggested Procedure for Moderate-Accuracy Requirements; Calibration Uncertainty in the Approximate Range of 0.01 nm to 0.1 nm: Connect the light source (either broadband or narrowband, as discussed above) to one of the fiber connectors on the SRM unit using a single-mode optical fiber terminated with a clean FC/PC connector. If the source power varies significantly with wavelength, divide the SRM transmission spectrum by the source spectrum to obtain a normalized trace. After identifying the absorption lines by comparing to the spectrum in Figure 1, make a high resolution scan of a line listed in Table 1. If the instrument has variable resolution, it is best to use a resolution of ≤ 0.1 nm with a data point density of at least one point every 0.005 nm. Find the wavelength readings on both sides of the line where the absorption is 50 % of the maximum; the line center is half-way between these two wavelength readings. Repeat this procedure five times and take the average of the five measurements for the line center. Calibrate the instrument to the center wavelength of this line (from Table 1) using the calibration procedure specified by the instrument manufacturer. The instrument's linearity can be checked by repeating the procedure for a different absorption line and comparing it to the value listed in Table 1.

Suggested Procedure for High-Accuracy Requirements; Calibration Uncertainty ≤ 0.01 nm: *[Note: due to the presence of weak nearby lines, background slope, and interference fringes, this SRM is not recommended for a calibration with an uncertainty of less than 0.001 nm.]* Connect the light source (either broadband or narrowband, as discussed above) to one of the fiber connectors on the SRM unit using a single-mode optical fiber terminated with a clean FC/PC connector. Divide the SRM transmission spectrum by the source spectrum to obtain a normalized trace. After identifying the absorption lines by comparing to the spectrum in Figure 1, make a high resolution scan of a line listed in Table 1. If the instrument has variable resolution, it is best to use a resolution of ≤ 0.1 nm with a data point density of at least one point every 0.001 nm. Using a fitting technique such as the least squares technique, fit the absorption data to the appropriate lineshape (Lorentzian if the line shape is dominated by the molecular absorption profile, Lorentzian convoluted with the instrument's filter characteristics if the instrument contributes significantly to the profile). Details of line fitting procedure and potential errors sources can be found in Reference [3]. Calibrate the instrument to the center wavelength of this line (from Table 1) using the calibration procedure specified by the instrument manufacturer. The instrument's linearity can be checked by repeating the procedure for a different absorption line and comparing it to the value listed in Table 1.

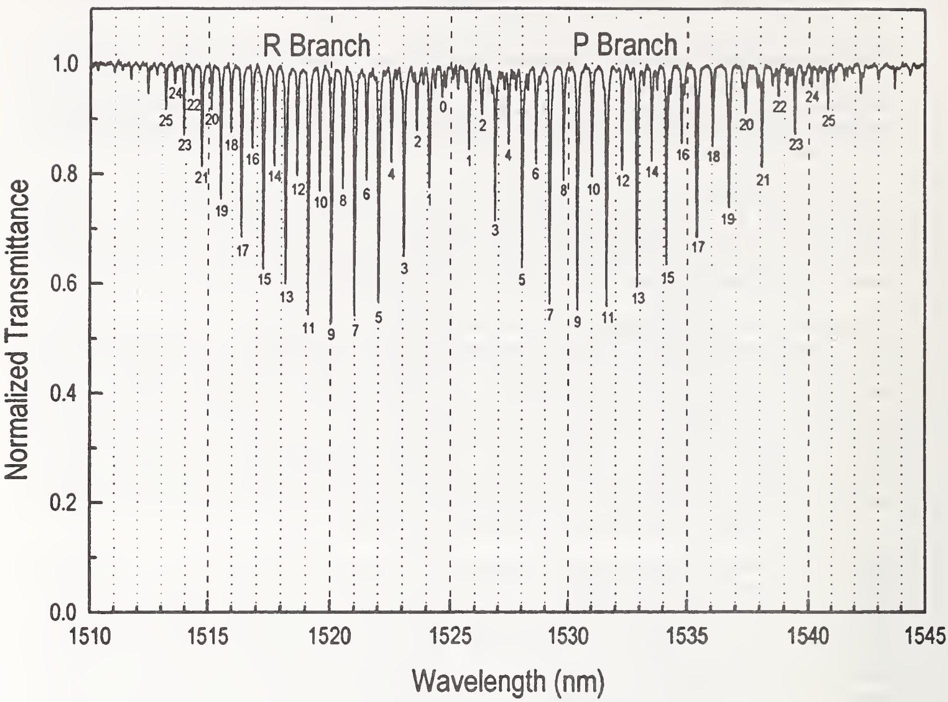


Figure 1. Acetylene ($^{12}C_2H_2$) spectrum taken by passing LED light through an absorption cell and recording the spectrum of the transmitted light using an optical spectrum analyzer with 0.05 nm resolution. This spectrum has been divided by the LED spectrum.

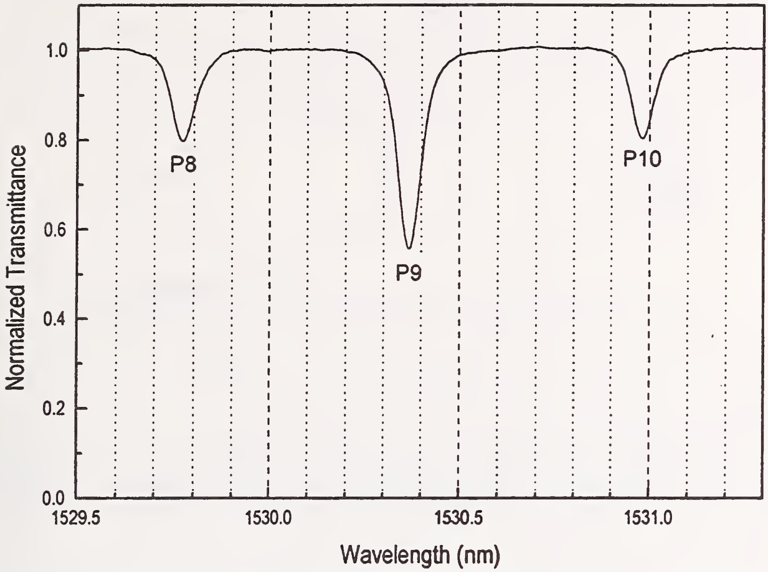


Figure 2. The P8, P9, and P10 lines from Figure 1 on an expanded wavelength scale to show lineshape.

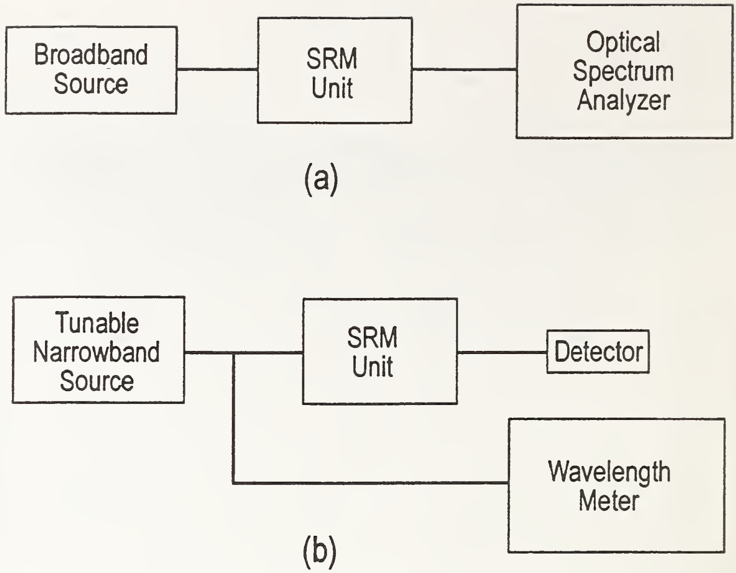


Figure 3. (a) Schematic of technique when using the SRM and a broadband source to calibrate an optical spectrum analyzer. (b) Schematic of technique when using the SRM and a narrowband source to calibrate a tunable laser or a wavelength meter. The wavelength meter is not required for a laser calibration.

REFERENCES

[1] Nakagawa, K., Labachelerie, M., Awaji, Y., and Kourogi, M., "Accurate Optical Frequency Atlas of the 1.5-μm Bands of Acetylene," J. Opt. Soc. Am. B **13**, pp. 2708-2714, (1996).

[2] Yoshida, T. and Sasada, H., "Near-Infrared Spectroscopy with a Wavemeter," J. Molec. Spectrosc. 153, pp. 208-210 (1992); Guelachvili, G. and Rao, K.N., Handbook of Infrared Standards II, Academic Press, San Diego, CA, pp. 564-568 (1993).

[3] Gilbert, S.L., and Swann, W.C., "Standard Reference Materials: Acetylene $^{12}C_2H_2$ Absorption Reference for 1510–1540 nm Wavelength Calibration - SRM 2517," NIST Special Publication 260-133 (1997). In Press.

[4] Edlen, B., "The Refractive Index of Air," Metrologia, **2**, p. 12, (1966); CRC Handbook of Chemistry and Physics 77th Ed., pp. 10-266, (1996).

It is the responsibility of users of this SRM to assure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at (301) 975-6776 (select "Certificates"), Fax (301) 926-4751, e-mail srminfo@nist.gov, or via of the Internet http://ts.nist.gov/srm.

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